By Tony Brock-Fisher, K1KP, and Bill Shaheen, N1CQ

Install a House-Bracketed Tower—the Right Way!

Which should move: the tower or the house?†

Often, the forces and stresses on towers and tower components are misunderstood, or worse, completely underestimated. Long-time ARRL Technical Advisor Bill Shaheen, N1CQ, and I designed a method of attachment that's capable of *properly* supporting a bracketed tower.[1] Here's how we did it.

As part of this year's station improvement plans at K1KP, I decided to relocate the 40-foot tower that stood behind the garage and increase its height. Now the tower is attached to the gable end of my two-story garrison house.

Part of the project's planning process involved securing the proper building permits from the local zoning board. In the last 10 years, there's been a significant increase in the amount of engineering data that must accompany an application for a permit to install a tower. This is surely a widespread trend, due to the increasing concern about liability and lawsuits. What this means to those of you contemplating the installation of a tower is twofold: First, be prepared to spend a significant amount of money for engineering work. Second, I strongly recommend that you erect the tallest tower you can. Although it's often a good idea to divide the space between your means and your dreams into manageable chunks, if you wait to install the tower of your dreams, it will likely be *much* more expensive in a few years! Many local building authorities rewrite their bylaws in ways that, while not outlawing Amateur Radio towers outright, may make them prohibitively expensive to install.

The local building authorities in my area now require that engineering plans—formulated by a state-licensed professional engineer—be submitted with the building permit application. To supply the required plans, I enlisted the services of Bill Shaheen, N1CQ. Bill is a structural engineer by profession and an expert in tower design and analysis. Bill first made a site visit to determine what the existing house structure could provide in the way of support. Then he designed and prepared plans for a support system that properly absorbs the forces acting on the tower.

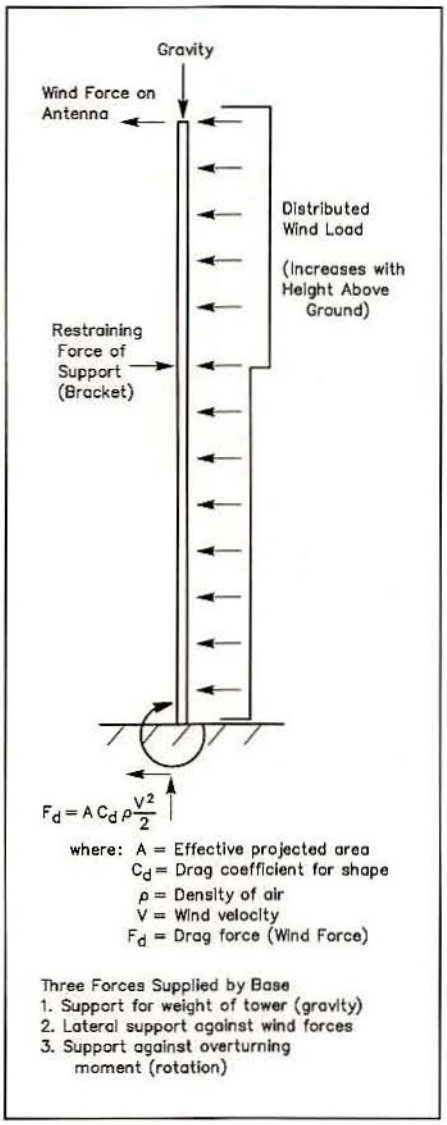
Gravity
Wind Force on Antenna
Distributed Wind Load
(Increases with Height Above Ground)
Restraining Force of Support (Bracket)
$F_d = A C_d \rho \frac{V^2}{2}$
where: A = Effective projected area
C_d = Drag coefficient for shape
ρ = Density of air
V = Wind velocity
F_d = Drag force (Wind Force)
Three Forces Supplied by Base
1. Support for weight of tower (gravity)
2. Lateral support against wind forces
3. Support against overturning moment (rotation)

Figure 1—This drawing shows the maximum expected forces that act on a bracketed tower.

Tower Forces—a Short Overview

Let's take a look at the two main forces that act on a house-bracketed tower: wind resistance and gravity. See Figure 1. The primary force requiring attention is the *wind force* that tries to push the tower over. Another force that may need to be carefully considered is *torque loading*, or twisting of the tower caused by wind acting on an aerodynamically unbalanced antenna, or by rotational forces transmitted to the tower by the antenna rotator during rotation.

The wind force acts on any antenna mounted at the top of the tower, and is dependent on the antenna's projected area. In my case, I planned to use a small triband beam with a wind-load area of about six square feet. The wind force also acts on the tower sections themselves, as they, too, have a significant projected area. The force of the wind acts on the entire tower and this force must be calculated and accounted for.

The method of calculation of lateral wind forces is shown in Figure 1. Another force acting on the tower is *gravity*. The tower must be able to support its own weight and the weight of all antennas, rotators and other equipment mounted on it.

In order to support the tower, the forces of wind and gravity must be balanced by other forces, which—in the case of a bracketed tower—are supplied by the bracket support and the base. The tower base is made of concrete, which provides support for the weight of the tower as well as resistance against the tower falling over. The tower is also bracketed to the house with one or more brackets part of the way up the tower. The brackets serve to prevent the tower from falling over.

†Neither.

[1]Notes appear on page 39.

Supporting a Tower

Basically, there are three methods of supporting a ham tower: by its base alone (otherwise known as self-supporting), by guy wires, or by attachment to a structure. Each means of support has its own set of advantages and disadvantages. I eliminated a guyed tower from consideration initially because there isn't enough room at the chosen location for guy wires. Rohn 25G tower sections were already available, so the installation was to be dictated by the strength characteristics of these components. The limiting factor on height above the support point of Rohn 25 typically is the wind loading of the tower and antenna. For an antenna like mine, if the support point itself is at the ground level—as in a self-supporting installation—the maximum tower height can be only 20 to 30 feet. By raising the support point to the house peak 30 feet above ground, the tower height can be 20 feet above this raised support point, reaching a reasonable antenna height of 50 feet.

Design Specifications and Conditions

When you design a tower installation, you must choose a certain set of environmental conditions the tower will be designed to withstand. This is usually dictated by your local building codes. In my case, the design wind speed is 85 mph. Also, in parts of the country where below-freezing temperatures are possible, freezing rain needs to be considered. In this case, the tower and support system is designed to withstand the additional wind loading and weight caused by 1/4 inch of radial ice. The ice significantly increases the projected area of the tower and antenna, but, unfortunately, doesn't add anything to the strength.

It's important to properly factor all the environmental considerations when designing your tower and support system. The Rohn catalog, for example, includes a chart that specifies the application of Rohn 25G tower in a bracketed installation. However, this chart clearly indicates *NO ICE*. Even if you're considering a cookbook tower installation, using information from a tower-manufacturer's catalog as a guideline, it's still a good idea to consult a professional engineer to ensure that all local factors have been taken into consideration. The ARRL can supply the name of an ARRL volunteer engineer in or near your area.[2]

Other environmental considerations include seismic loads and weather-related factors other than ice. At my location, these other factors were not significant enough to require study.

The required strength of the bracket and the base are determined to a large extent by the tower height and the height of the attached bracket. Originally, I wanted a 60-foot tower. Bill's analysis, however, showed that, with the environmental conditions we had to consider, this wasn't possible. This is an example of valuable information that a professional engineer can provide: information that leads to a design iteration, where the tower specifications are changed and the design is reanalyzed in an iterative process to arrive at a safe, strong design. There were at least three alternatives: reduce the height to 50 feet; guy the tower for more support; or use stronger components, such as upgrading to Rohn 45G from Rohn 25G. Because the tower components had already been purchased and there was no room for the guys, I compromised with a 50-foot tower.

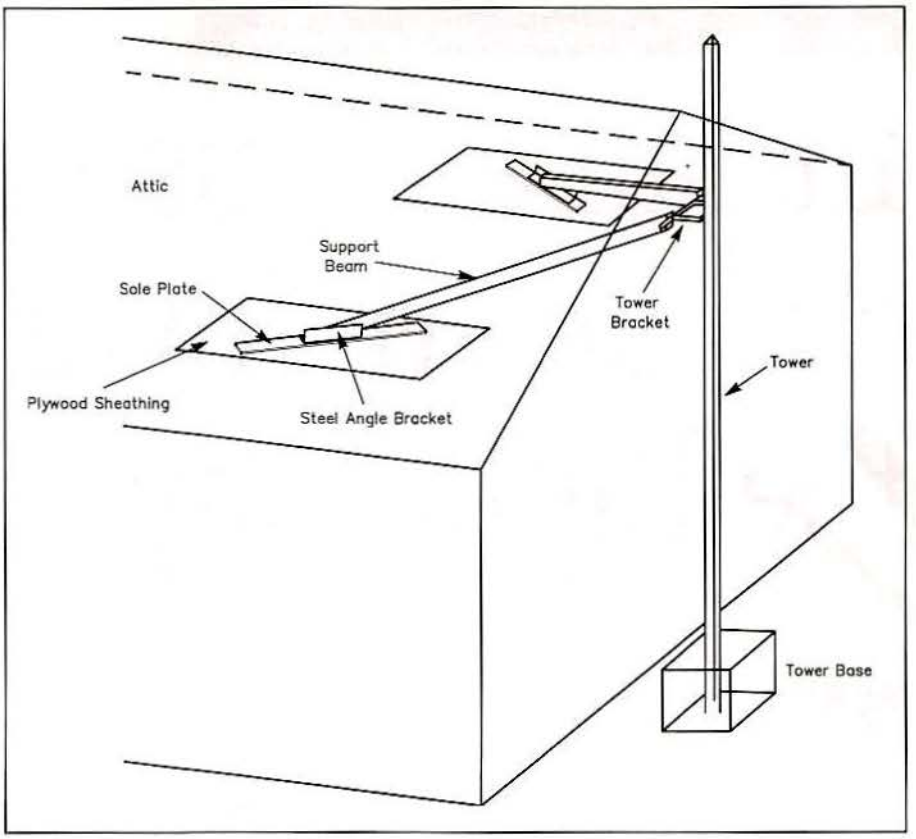

Figure 2—Two lateral support beams transfer the wind forces from the tower to bearing pads attached to the attic floor.

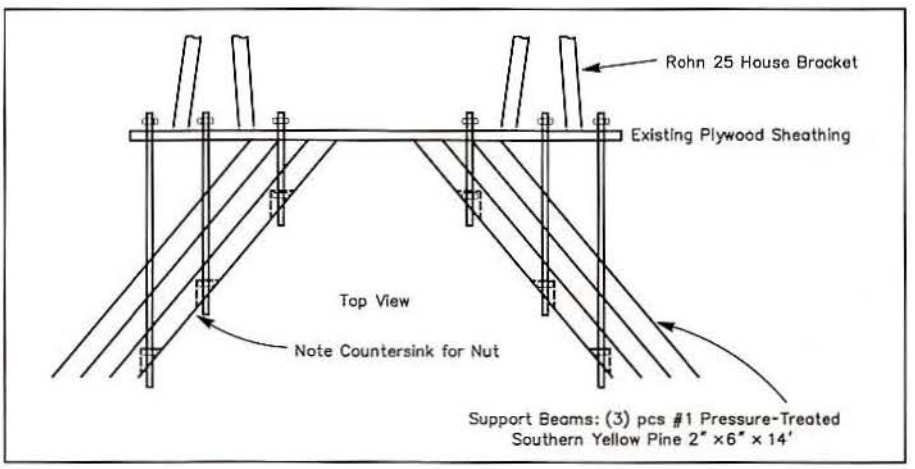
Rohn 25 House Bracket
Existing Plywood Sheathing
Top View
Note Countersink for Nut
Support Beams: (3) pcs #1 Pressure-Treated Southern Yellow Pine 2" ×6" × 14'

Figure 3—The tower's primary support bracket area (as viewed from the roof), showing the interior studs have been removed to provide access to the inside surface of the house sheathing (see Figure 4). B, a side view of the two support beams.

The Bracket and Support

Bill's analysis showed that at maximum wind and ice loading, there would be a horizontal force of 1111 lb at the bracket. That's over a half ton of force! Such force can't be handled by a couple of bolts through existing house-wall studs. A properly designed bracket support is needed to transmit this force to the house without tearing the house apart!

Bill's approach is shown in Figure 2. In the attic, behind the primary support bracket, two large beams are mounted to connect the bracket to the attic-floor joists. The beams are placed at angles to each other and the gable end wall. The angle selected provides good rigidity to forces parallel to the gable end wall, as well as perpendicular to it. It's almost as if

the tower is guyed with wooden guys.

The beams also angle downward and connect to the attic-floor joists. This way, the lateral force from the bracket is transmitted to the attic floor joists. The force is spread to five floor joists for each of the two support beams. The force each particular joist receives is divided to a fraction of the total force.

Construction Details

Each beam is made of three 2×6-inch pieces of lumber, 14 feet long. The lumber used must be capable of withstanding the expected forces, with a safety factor included. Also, any support components made of wood must be derated to account for any possible degradation of the material over time. In this case, commonly available #1 grade pressure-treated southern yellow pine meets these requirements. (Pressure treating doesn't add anything to the strength; it's just the most common construction lumber available that meets the strength requirement.)

Beams—Bracket End

At the bracket end of the beams, there needs to be flush, intimate contact between the beam ends and the inside of the plywood sheathing at the attic gable end. This allows the forces to be cleanly transmitted into the beams without involving any of the gable end studs. To eliminate the studs, the interior framing of the gable end is modified. See Figures 3 and 4. The job is identical to installing a window, except the plywood sheathing is left intact. Carefully determine the width of the affected area, based on the size of the house bracket. Temporarily support the ridge pole while the studs are cut away and a new header is installed to take over the job of supporting the studs.

After the bracket area is clear of studs, install a 2×4 cross brace on the inside of the studs that were left in place. Install the brace about four feet above the attic floor. This provides a place for the beams to rest while you're measuring and marking them for the end cuts and drilling the landing pad end. The beams are heavy! This cross brace establishes the height of the primary tower bracket, which is nominally four feet above the attic floor.

With the cross brace in place, rest the beam on the brace and mark the end of the beam for the compound angle to be cut. The goal here is to make the end of the beam fit flush against the plywood when the beam is in place. You may want to experiment a bit to get the angle just right, before attempting a final cut on the expensive lumber. Once you get the angle figured out, you can cut the same angle on all three 2×6s for each side. It's an opposite angle, of course, from one side to the other. After the bracket ends are cut, cut the landing pad ends so that the three ends are flush when the beams are in place against the sheathing.

Landing Pads

On the attic floor, first tie the joists together with a sheet of ¾-inch-thick exterior grade plywood at each beam's "landing pad." See Figure 5. Secure the plywood to the joists with 8d common nails, spaced six inches on center. The plywood landing pad is 64 inches square. Locate any joints in the plywood at the *center* of a joist, and nail both pieces of plywood to the joist. It's a good idea to add blocking pieces, of the same width as the joists, between the joists used for attachment. This blocking provides more lateral strength and prevents the joists from twisting.

On top of the plywood, nail a 72-inch-long piece of #1 grade 2×6 pressure-treated southern yellow pine using 10d common

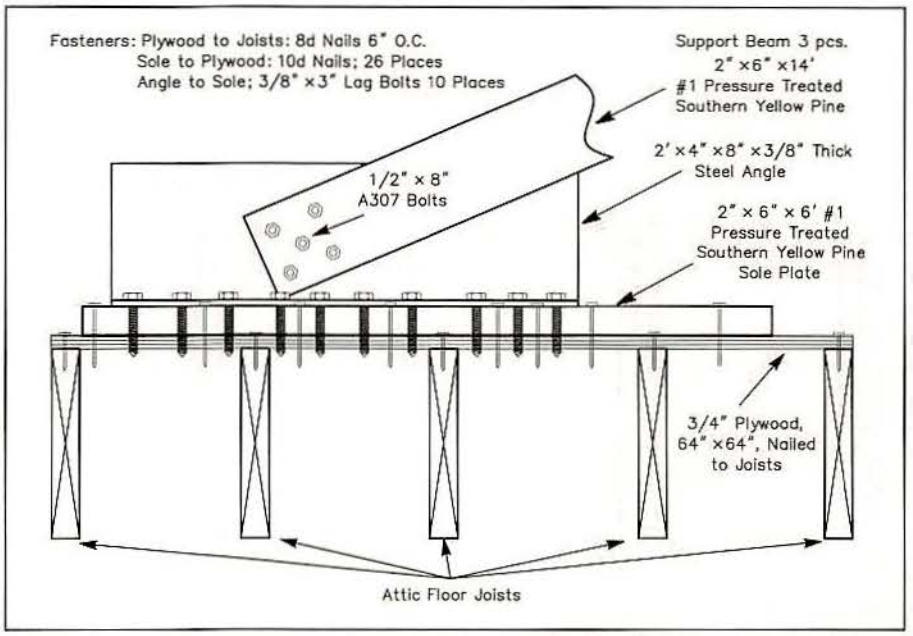

Figure 5—Side view of the attachment of the lower end of a support beam to a bearing pad on the attic-floor joists (see Figure 6).

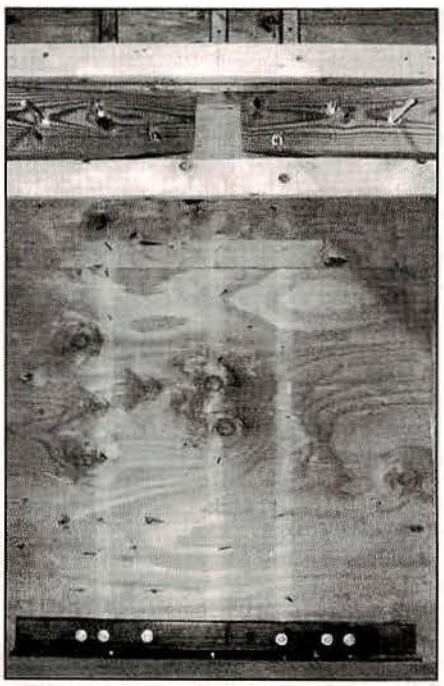

Figure 4—An inside view of the tower's primary bracket support area, showing the attachment of the two support beams running diagonally to the left and right (see Figure 3). The steel angle at the bottom is attached to the tower's secondary bracket support area (see Figure 8).

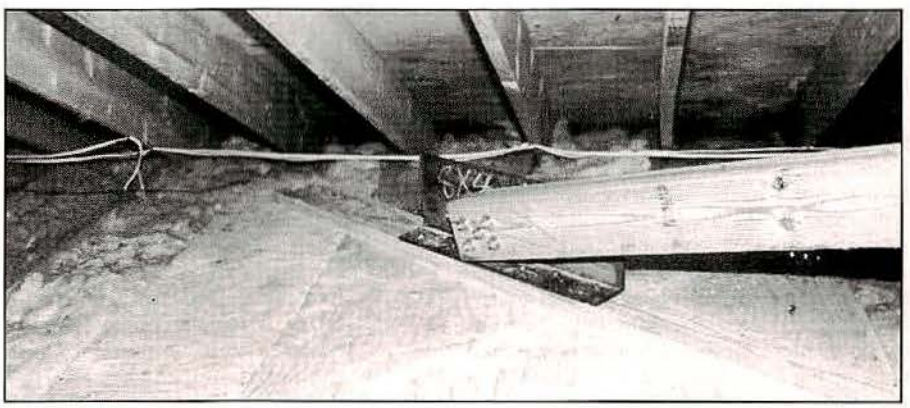

Figure 6—The lower end of a support beam (one of two) and its attachment to the bearing pad on the attic floor (see Figure 5).

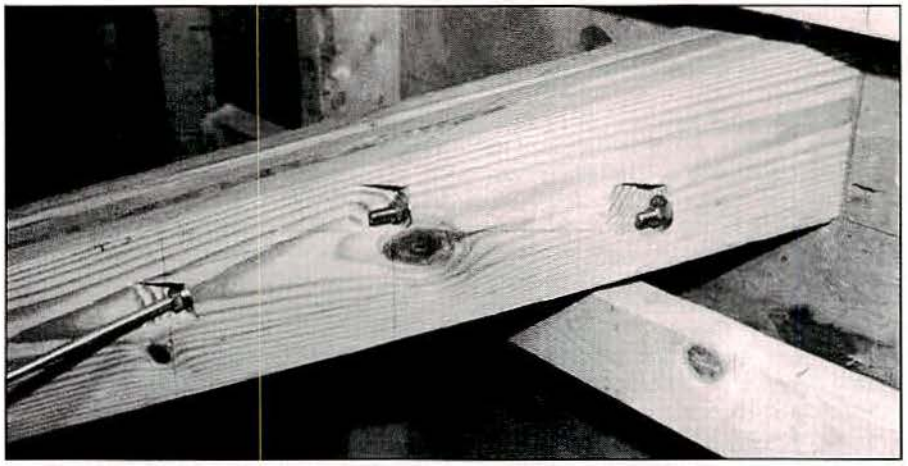

Figure 7—A close-up of the attachment of the upper ends of the support beams at the tower's primary bracket-mounting area. Note how bolt holes are countersunk to provide flush seating for the nuts and washers.

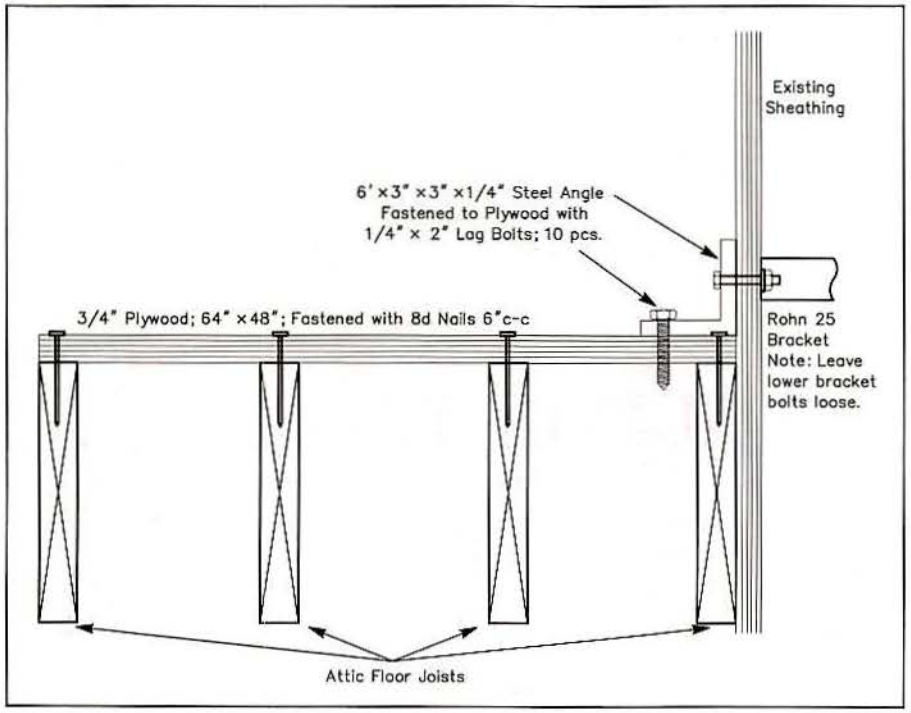
Existing Sheathing
6' x 3" x 3" x 1/4" Steel Angle Fastened to Plywood with 1/4" x 2" Lag Bolts; 10 pcs.
3/4" Plywood; 64" x 48"; Fastened with 8d Nails 6"c-c
Rohn 25 Bracket Note: Leave lower bracket bolts loose.
Attic Floor Joists

Figure 8—Side view showing the attachment of the tower's secondary support bracket to the attic floor using 3-inch-wide steel angle and 3/4-inch-thick plywood.

nails (at least 26 nails each). This sole plate provides an attachment point for a piece of steel angle that forms the attachment of each beam to the landing pad. The steel angle is 4×8 inches by 3/8 inch thick. Drill 10 holes in the 4-inch web to allow lag-bolting the steel to the sole plate with 3/8×3-inch lag bolts. Predrill holes in the base to accept the lag bolts. Stagger the hole placement to maximize strength. Drill five holes in the 8-inch steel angle web to provide an attachment for the beam; use 1/2-inch-diameter steel bolts, flat washers, lockwashers and nuts. Lay out the bolt pattern for this attachment such that none of the holes is closer than 1 3/4 inches from the edge of the beam or from each other. Knowing from Bill's plans that the beams would attach at a 17° angle, I first drilled the holes in the steel (a computer drawing program was used to locate the holes). Once the steel was lag-bolted in place on the floor, the beams were held in place with a C clamp while the wood was drilled. See Figure 6.

Primary Bracket

After checking the trial fit of the beams at the gable and landing-pad ends, mark the plywood sheathing where the ends of the beams butt up against it. Then remove the beams and carefully mark the wall for the hole pattern that will be used for the primary house bracket. The holes must not be closer than 1 1/2 inches to the edge of the beams. This means that the bracket height must be carefully set so that the inner holes are not too close to the bottom edge of the beam; and the outer holes are not too close to the top. If the holes come too close to the top beam edge, the bolt hole has to be drilled at a downward angle to maintain the 1 1/2-inch distance to the edge.

After locating the holes on the sheathing, they can be drilled from the inside. Next, position the beams in place and drill the bolt holes through the beams from the outside. (You'll probably need to do this from a ladder.) Have a helper inside position the tip of the drill at the correct spot on the outer side of the beams before you start drilling. With the tip positioned properly on the beams, and using the holes in the exterior sheathing to guide the drill bit, you should be able to drill through the beam for the mounting bolts.

After all the holes are drilled in the beams, use a wood chisel to cut countersinks around the bolt holes so that the nut and washer will have a good flat area to bear on. See Figure 7.

Secondary Bracket

Although the primary bracket is designed to withstand the full expected loading of the tower under the design conditions, it might not be a bad idea to include a secondary bracket "just in case." Here, a second house bracket is added at the attic floor level. A piece of 3/4-inch-thick plywood is nailed to the attic floor joists just beneath the primary bracket. This piece of plywood extends right up to the exterior sheathing. A 3×3×1/4- inch-thick piece of steel angle is used to make the connection between the plywood and the secondary bracket.

See Figure 8. Use ten 2-inch long 1/4-inch-diameter lag bolts to secure the steel angle to the new plywood. The other side of the angle is drilled to match the house bracket.

Leave the secondary bracket loose. The hardware should allow 1/2 inch of tower movement. Why? If the second bracket is fastened tightly, it increases the bracket forces on the tower section at the primary bracket because the bending conditions in that vicinity are modified.

Base

The base that Bill designed is significantly more sturdy than the one specified in the Rohn catalog. Again, the specific local conditions, including soil conditions, dictated that a base larger than normal was needed. Although Bill's design calls for a 30-inch round base, a 30-inch square base can be used. I chose the latter because plywood forms were already available from an earlier tower-base project. The plywood forms are much less expensive than a Sonotube form. Resist the temptation to merely dig a hole in the ground and pour the concrete directly into the hole. We constructed a steel reinforcing-bar (rebar) cage of 3/8-inch (#3) and 1 1/8-inch (#9) rebar pieces, which are tied together with steel wire.[3] This cage is tied in position outside a short piece of tower section used for the base.

Prepare the hole bottom by adding a few inches of drainage material such as sand or gravel. The bottom tower-section legs must project into this material. *Be very careful not*

to allow the tower legs to become blocked by the concrete—water can become trapped in the legs and cause accelerated tower failure because of corrosion (rust). Worse yet, the water can freeze and split the tower legs above the concrete.

Position the base section exactly plumb and align it with the bracket work above. The most straightforward and foolproof way of doing this is to install as much tower as will reach from the base to the bracket. There are two approaches you can take: You can raise two or three sections Field-Day style. Alternatively, you can lift the sections one at a time with a block and tackle, and lower each one into position on top of the section below. If the house bracket is installed, you can use it as a lift point—if you attach the block and tackle close to the house.

When the forms are positioned in the hole and the base section is secured in the forms, you're ready for the concrete. The minimum strength of the concrete should be 3000 PSI. If you use wood forms, they'll have to be removed after the concrete has cured. Therefore, it's important to prevent any concrete spilling down the *outside* of the forms, as it will harden and effectively lock the forms in the ground. Use plywood scraps to cover the outside of the forms and catch any spilled concrete.

If you're lucky, the concrete delivery truck will be able to get close enough to the hole so that the concrete can be directed into the form with the truck's chute. If not, you'll need about three wheelbarrows (and at least as many friends who don't have back problems!) to ferry the concrete from the truck to the hole. As an estimate, one cubic yard of concrete swallows 12 to 16 wheelbarrow loads (depending on the size of your wheelbarrow).

Summary

This design has been analyzed by a professional engineer and certified to provide the strength to properly support the tower described with the existing structure and with local soil conditions. Whether your local building codes and authorities require your construction be professionally analyzed or not, consider what might happen to your property (and you) if the tower is *not* properly supported.

This article describes a tower installation for a particular set of circumstances. It is in no way meant to specify any portion of any design for any other set of circumstances. No liability, expressed or implied, is assumed for any use of the information. Be sure to consult a professional engineer before erecting *your* tower!

Notes

[1]See Allan Fusler, KI7NF, "The Importance of Proper Tower and Mast Design," *QST*, Jan 1996, pp 77 to 78 and "Welding Reinforcing Bar," Apr 1996, p 79.—*Ed.*

[2]For the name of the volunteer consulting engineer nearest you, contact Lisa Kustosik at ARRL HQ, tel 860-594-0200, e-mail **lkustosik@arrl.org**.

[3]See Note 1.

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Bill Shaheen, N1CQ, earned BS and MS degrees in civil engineering from the University of Massachusetts in 1983 and 1985, respectively. Bill received his PhD in civil engineering from the University of Connecticut in 1991. Bill is Vice President and Chief Financial Officer of Analytical Engineering, Inc of Granby, Massachusetts. He's also an adjunct faculty member in the civil engineering department at the University of Connecticut. Bill enjoys DXing, and is frequently found on 3.795 MHz working the gray line. You can contact Bill Shaheen, N1CQ, at 49 South Street, Granby, Massachusetts, 01033; voice tel: 413-467-3141; fax 413-467-9075.

Amateur Radio World

IARU on the Road to Rio: Americas TELECOM 96

Twenty-five years ago, the International Telecommunication Union (ITU) created the TELECOM trade exhibition to showcase the telecommunications industry, and an accompanying forum where exciting trends in technology transfer and policy issues could be discussed at a high level. The silver anniversary TELECOM was celebrated in June 1996, with the holding of a regional trade show and forum in Rio de Janeiro.

And quite a show it was. It was the 16th TELECOM event, and the largest of the regional events held so far. There was just under 195,000 square feet of exhibition space, 412 exhibitors from 25 different countries, and more than 18,000 visitors. However, just to keep this in perspective, the World TELECOM in Geneva in September 1995 was approximately five times as large by all measures.

IARU Region 2, the International Amateur Radio Union organization for the Americas, was invited to mount a stand to tell about Amateur Radio. About 325 square feet of exhibit space was available for photographs and posters showing the AMSAT Phase 3-D project, typical scenes of amateurs assisting in disaster communication, and publications by IARU radio societies.

On hand from IARU Region 2 for the entire week were President Tom Atkins, VE3CDM, Vice President Ron Szama, LU2AH, Secretary Pedro Seidemann, YV5BPG, and Director Eduardo Estrada, HC2EE. I had gone to Rio for a meeting of the Region 2 Executive Committee the previous weekend, and stayed to help. LABRE, the Brazilian IARU member-society, provided valuable assistance, particularly Marcelo, PY1KN, and LABRE national president Oms, PY5EG.

A select group of 1400 participated in the forum. For the first time in the 25 years of TELECOM, a special session on emergency communication was organized under the leadership of M. Harbi, special assistant to the ITU secretary-general. The three main invited speakers in this session were Hans Zimmermann, senior officer of the UN Department of Humanitarian Affairs (Geneva); Jay Rushby, head of telecommunications of the office of the UN High Commissioner for Refugees (Geneva); and IARU Region 2 President Tom Atkins, VE3CDM (Toronto).

Hans Zimmermann concluded his presentation by offering "special thanks" to ham radio, which he described as "a mainstay of emergency telecommunications."

"The Amateur Service provide the best qualified operators for emergency telecommunications, which requires flexibility, ingenuity and improvisation. The Amateur Radio Service also provides a unique, worldwide, decentralized network of highly disaster-resistant stations," Zimmermann declared. He appealed to policymakers "to facilitate and to encourage the development and the use of this unique and entirely voluntary, and at the same time highly professional, public service."

IARU Region 2 President Tom Atkins, VE3CDM, spoke on behalf of the Amateur Service. He addressed our history and tradition of contribution during emergencies, taking particular note of events that have occurred in the Americas, including storms, floods, earthquakes and volcano eruptions. Tom also discussed the CITEL/OAS initiative to establish an International Amateur Radio Permit (IARP) as a way to facilitate the movement of operators and possibly equipment across international borders.

A number of favorable comments about the role of amateurs were made during the question and answer period that followed.

Amateur Radio was presented in a positive manner to TELECOM visitors, other exhibitors, telecommunications professionals, and the many visiting amateurs from other countries who stopped by to sign our guest book and just to say hello to a fellow ham. We didn't make DXCC but did greet quite a few well-known amateurs who were present in their business capacities.

Would I go to the next TELECOM if invited? You bet!—*Larry E. Price, W4RA, ARRL Vice President, International Affairs*